Third Party Review Meeting
and
International Review Group

Summary of Independent Findings of the 2nd Review
June 3rd – 5th 2014

Evaluation of Faults Near the Tsuruga Nuclear Power Plant

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5th June 2014

1 Context

The Third Party Review Meeting (TRM) and Independent International Review Group (IRG) visited Tsuruga in July 2013 and examined the evidence related to the activity of faults in the bedrock at Tsuruga NPP. We submitted a report to JAPC on 28th August 2013 providing our views on the issue of fault activity and making recommendations for how JAPC and NRA might proceed based upon internationally recognised methodologies (the International Atomic Energy Agency, IAEA, an agency of the United Nations) for resolving such issues. In simple terms, we agreed with JAPC's finding that the specific faults of concern to NRA (G/D-1 and K) are not active, according to NRA's definition of 'activity'. Our main recommendation was for JAPC and NRA to consider working together so that the seismic hazard analysis of the NPP can be continually improved and updated with new data and techniques, as they arise ('living safety assessment'), based on the most up-to-date international standards.

Subsequently, in January 2014, NRA has visited Tsuruga NPP with an expert group to evaluate the 2013 JAPC information but has not significantly changed its position from May 2013 (that the G/D-1 and K faults are 'active').

We have reviewed additional material supplied to us by JAPC on 26th May 2014, including:

- Material presented by JAPC to NRA on 14th April 2014;
- NRA presentations on 14th April 2014.

We have also revisited the Tsuruga site this week to examine the physical evidence again.

Our overall finding is that *there is no need to change the conclusions in our international review report* dated 28th August 2013.

2 The G/D-1 Fault

The inactivity of the G/D-1 fault (based on NRA's definition of activity) no longer seems to be a disputed issue. The NRA experts have not raised any further issues about this fault since last year. G/D-1 has completely different characteristics to the K fault and it is an old fault with no evidence of activity since the oldest superficial sediments (Layer 1) were deposited. There is certainly no evidence of activity in the last 130,000 years.

This means that there is no active fault beneath Tsuruga NPP Unit 2.

3 The K Fault

Assessment of the time of the last movement of the K-fault is based on information from volcanic ash (tephra) layers in the sediments that overlie the fault (particularly in Layer 5) and from the structure of the fault.

3.1 Age of the tephra

The tephra in Layer 5 (L5) is of low concentration, so a broad range of evidence is needed for robust identification. The Mihama tephra has a distinctive chemical composition and is a particularly useful time marker (age 127,600 years) in the sediments lying above the faults being studied. It is used to bound the time of the last activity of the G/D-1 and K faults.

There is some scatter in the major element cross-plots, but overall the data are comprehensive and show good correlation with the tephra in the Tsuruga Bay marine borehole core and the Mihama tephra type locality. JAPC has studied Mihama tephra distribution and characteristics across a wide regional area around Tsuruga (up to about 60 km away). JAPC has supplemented chemical analytical data on hornblende phenocrysts (crystals that are part of the tephra) by evaluating the chemistry of orthopyroxene phenocrysts.

We note that JAPC has responded to our previous recommendation to carry out a statistical analysis of hornblende chemistry, which provides convincing correlation of hornblende phenocrysts in lower L5 with the Mihama tephra. The concerns of NRA's experts that the characteristics of the Mihama tephra are different at different locations is not considered relevant, as such variations in thickness and degree of weathering, for instance, are to be expected.

The phenocryst concentrations can be correlated with distinct silty sand/gravel sediment horizons in lower L5 and are not mixed throughout L5. The absence of phenocrysts in the lowest part of L5 is indicative that the sediments below the Mihama tephra are older and that there has not been upward mixing of material into the Mihama tephra. This latter possibility seems to have been a major concern of NRA's experts. We deduce that the emplacement of Mihama tephra took place primarily by air-fall. There has been some later re-working (for example, by rainfall), but this took place very early in the deposition of the L5 sediments. The lowest part of L5 is thus older than the Mihama tephra and the fact that it is not cut by the K fault establishes that the fault movement must be older than 127,600 years.

The sediments above and below the Mihama tephra have also been demonstrated to be the same (terrestrial deposits) in both the Tsuruga D-1 trench and several borehole cores. They record the transition from Pleistocene stage MIS 6 deposits, upward into MIS 5 deposits, approximately 130,000 years ago.

Pollen analysis provides independent evidence for a warm climate during the period in which the Mihama tephra from Tsuruga Bay marine core and lower L5 was deposited and is thus well correlated to MIS 5e age, which was the last interglacial warm period. The sedimentary transition from terrestrial gravel to shallow marine deposits in the Tsuruga Bay marine core, in the section described by Yasuno in 1991, illustrates the transgression of the sea across a former land area as the climate warmed. Although this sedimentary transition is not so clear at the D-1 trench, multiple lines of evidence from tephra, pollen, and stratigraphic correlations to other sites combine to provide a robust and confident basis for assessment at the D-1 trench.

3.2 K-fault activity

We consider that it is possible that the K fault was caused by movement on the Urasoko Fault. The same view is expressed by one of the NRA experts who suggested that it is a secondary fault, resulting from movement on a primary seismogenic fault – here, the Urasoko Fault. We consider that this probably occurred as a single event. We therefore consider that a rapid reduction in slip toward the end of a secondary fault is to be expected, especially if it lies within the narrow 'damage zone' of a primary seismogenic fault.

In this respect, a key observation is that the evidence indicates that the movement does not extend more than about 60 metres from the Urasoko fault at any point and its last identified location with any minor movement prior to the Late Pleistocene is about 270 metres from NPP Unit 2.

The K fault has an upper termination in L3. **There is no evidence for activity during the Late Pleistocene on any of the exposures in trench D-1.**

Therefore the K fault cannot be classified as 'active' according to NRA's definition.

We also note that JAPC has re-evaluated the displacement pattern on K using an updated and improved geometrical approach. This has produced broadly similar values to those from their 2013 analysis. Regarding the upper termination of the K fault on the NW wall of the D-1 trench, a concern of a NRA expert was that "displacement is bigger at the lower part of outcrop and it decreases or vanishes at the top of L3.". If this were true, the most recent rupture on the K fault might have taken place at any time after the deposition of L3. However, JAPC analyses of displacement and deformation clearly demonstrate that a similar amount of total displacement and deformation terminates within L3, not at the upper surface of the layer. Therefore, the most recent rupture of the K fault was within the age of L3.

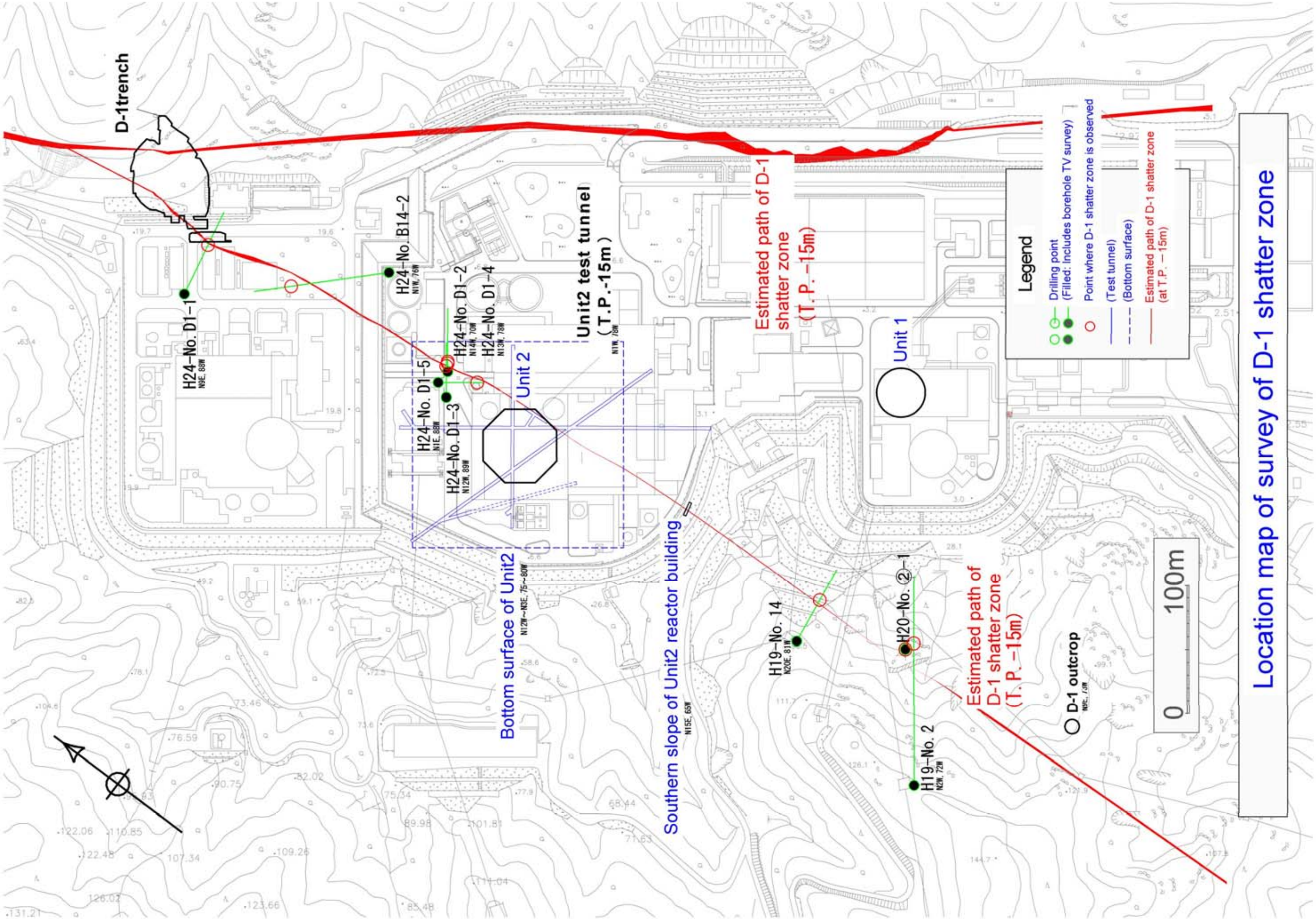
4 Looking forwards

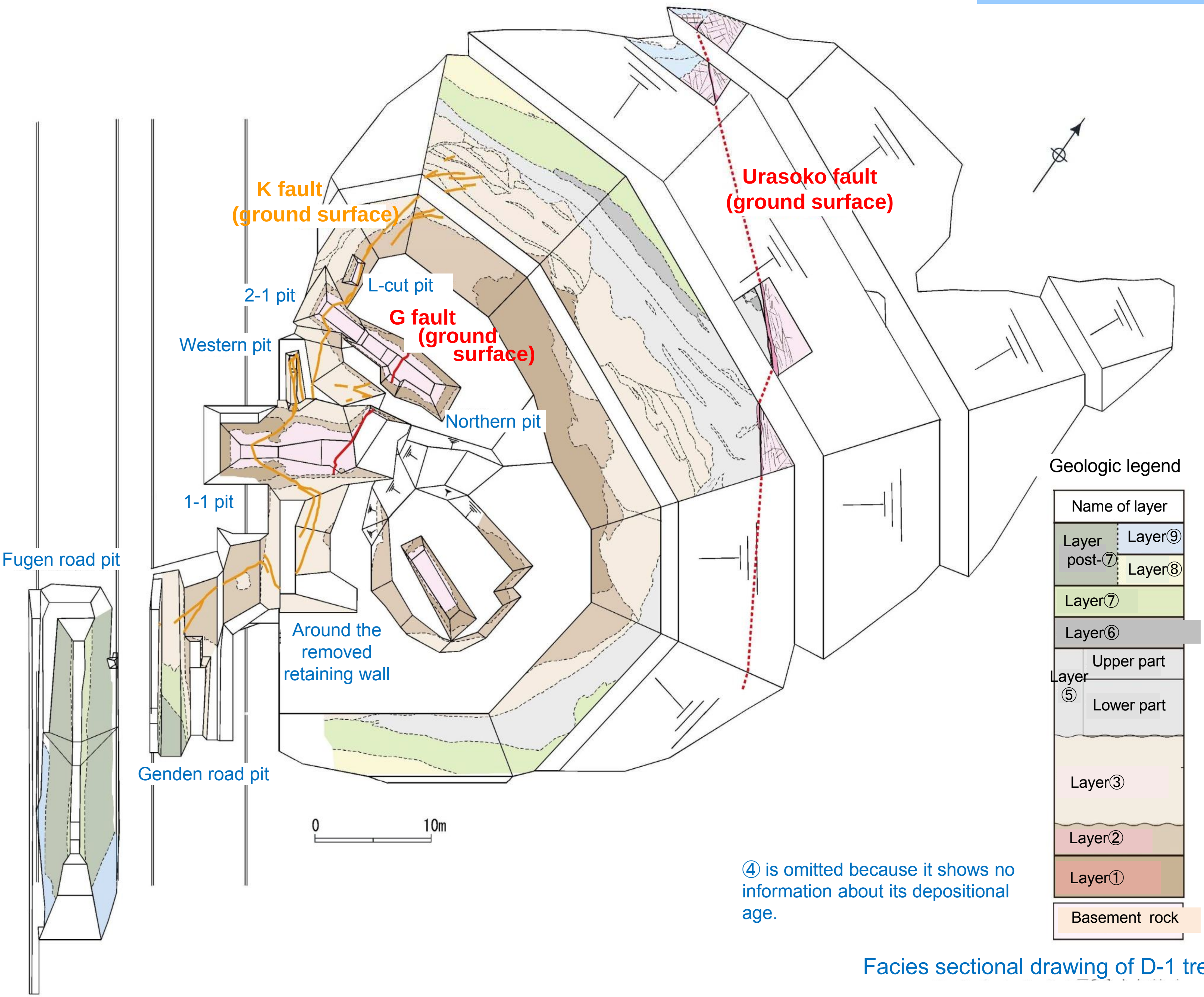
There is clearly need for better dialogue between NRA and JAPC. We reiterate our key observations from last year:

- **there is clear evidence that the K and G/D-1 faults at the Tsuruga NPP are not active: they have not moved in at least the last 120,000 to 130,000 years;**
- **there is a sound scientific basis for JAPC and NRA to enter a dialogue on continuing and improving (*kaizen*) the seismic safety evaluation and management of the NPP.**

Materials for the NRA export review meeting of April 14, 2014

Location map of survey of D-1 shatter zone

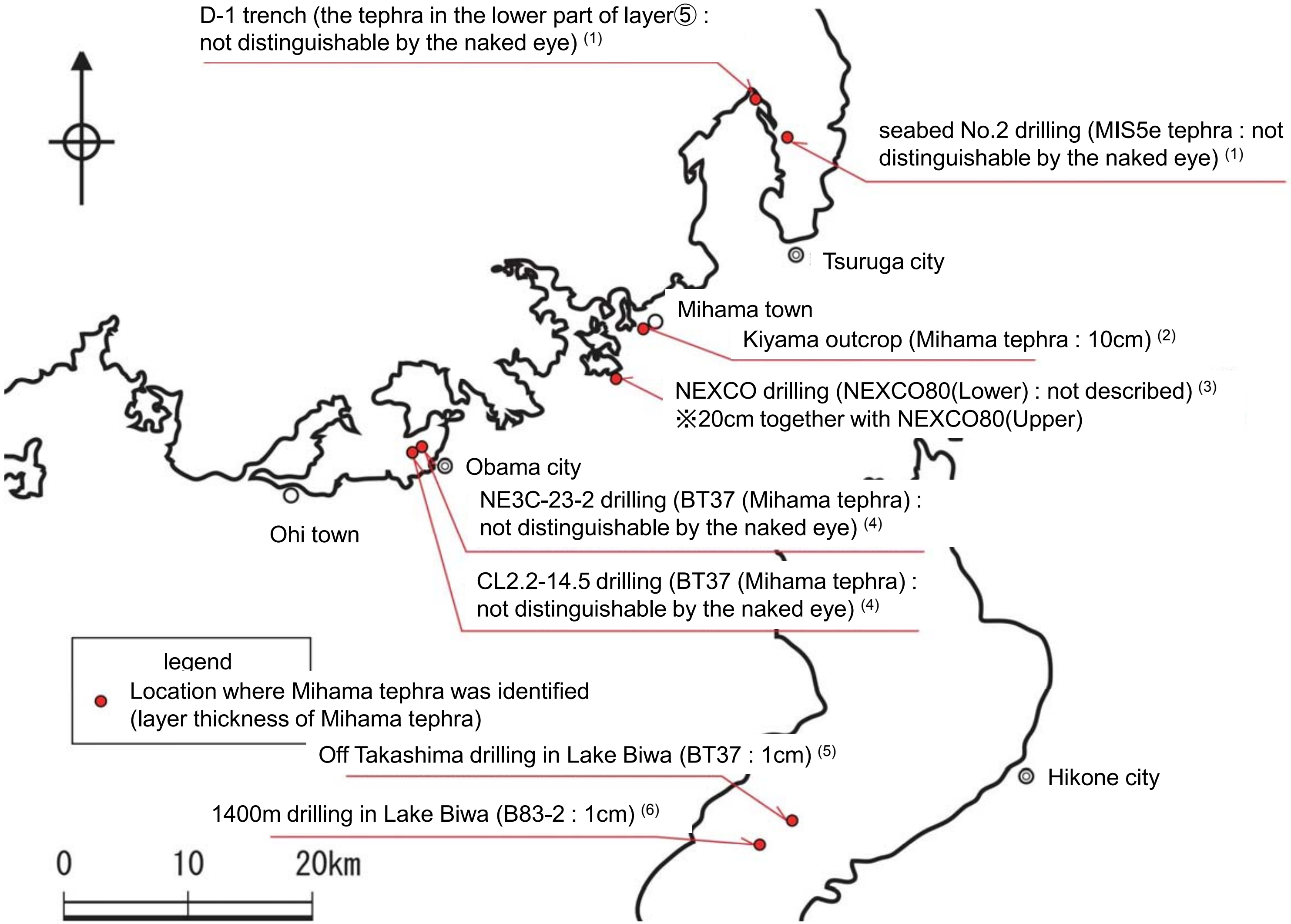




④ is omitted because it shows no information about its depositional age.

Facies sectional drawing of D-1 trench

Identified location and layer thickness of Mihama tephra



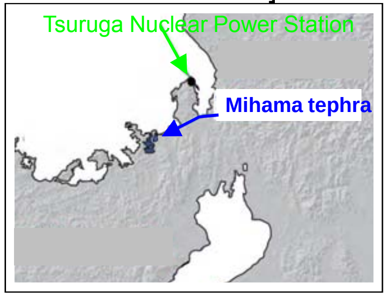
(1) Analyzed by JAPC
(2) Yasuno,T (1991) Discovery of Molluscan fossils and a tephra layer from the Late Pleistocene Kiyama Formation in the west of Fukui Prefecture,central Japan. *Bull. Fukui Mus. Nat. Hist.*, no.38,p9-14
＊露頭名は(2)文献による。テフラの層厚は日本原子力発電株式会社が計測
(3) 石村大輔, 加藤茂弘, 岡田篤正, 竹村恵二 (2010) 三方湖東岸のボーリングコアに記録された三方断層帯の活動に伴う後期更新世の沈降イベント, 地学雑誌, 119(5), p775-793
(4) 関西電力株式会社(2013) 大飯発電所、高浜発電所 FO－A～FO－B断層と熊川断層の連動に関する調査結果 コメント回答, 125p
(5) 長橋良隆, 吉川周作, 宮川ちひろ, 内山 高, 井内美郎 (2004) 近畿地方および八ヶ岳山麓における過去43万年間の広域テフラの層序と編年 －EDS分析による火山ガラス片の主要成分化学組成－, 第四紀研究, 43(1), p15-35
(6) 壇原 徹, 山下 透, 岩野英樹, 竹村恵二, 林田 明 (2010) 琵琶湖1400m掘削試料の編年：フィッション・トラック年代とテフラ同定の再検討, 第四紀研究, 49(3), p101-119

No literature indentify the source of Mihama tephra.

Point at issue 1 - Age of the D-1 trench's geological strata (lower part of layer⑤)

The Japan Atomic Power Company (4th evaluation meeting of April 24, 2013)

[Identification of volcanic ash]



	Layer⑤ lower part tephra		Mihama tephra
hornblende	Refractive index	=	Refractive index
	Main ingredient composition	=	Main ingredient composition

Older than Sanbe-Kisuki (110,000 to 115,000 years ago) (Yasuno.T(1991))

Tephra in the lower part of layer⑤ = Mihama Tephra

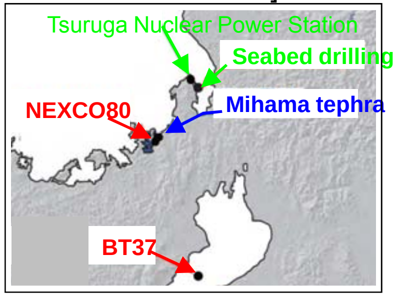
Evaluation meeting (7th meeting of the Nuclear Regulation Authority of May 22, 2013)

Hornblende only would be insufficient.

The possibility has merely been suggested, and not proven in terms of stratigraphic sequence.

The Japan Atomic Power Company (Reports of July 11, 2013)

[Identification of volcanic ash]



	Layer⑤ lower part tephra		Seabed drilling MIS5e		Mihama tephra		NEXCO80 (lower)		BT37
Hornblende	Refractive index	=	Refractive index	=	Refractive index	=	Refractive index	=	Refractive index
	Main ingredient composition	=	Main ingredient composition	=	Main ingredient composition	=	Main ingredient composition		
Rhombic pyroxene	Refractive index	=	Refractive index	=	Refractive index	=	Refractive index	=	Refractive index
	Main ingredient composition	=	Main ingredient composition	=	Main ingredient composition	=	Main ingredient composition		
Volcanic glass							Refractive index	=	Refractive index
							Main ingredient composition	=	Main ingredient composition

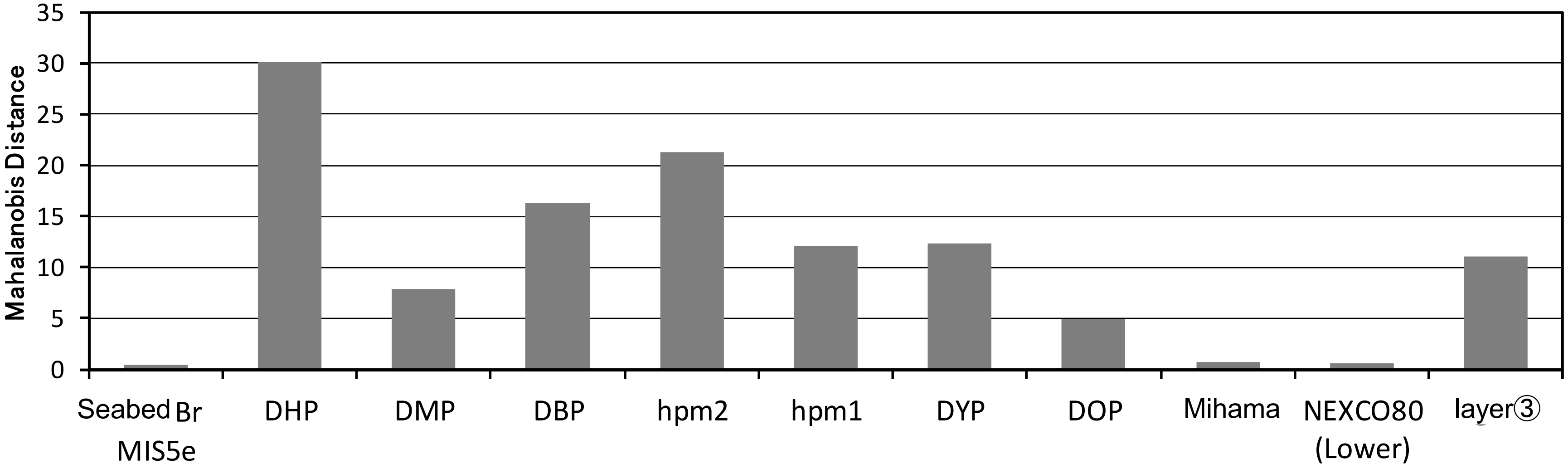
127,600 years ago (Nagahashi et al. (2004))

Tephra in the lower part of layer⑤ = seabed drilling MIS5e = Mihama tephra = NEXCO80 (lower) = BT37

The tephra age of the tephra in the lower part of layer⑤ is correlated with BT 37, and is therefore about 127,000 years ago.

Opinions on matters to be verified. [Point at issue 1] (1) 2.

In the correlation of the results of analysis on the main ingredient composition of hornblendes, provide explanations, citing evidence, on the criteria based on which some tephra was found to resemble the tephra in the lower part of layer⑤ and some was found to be different.

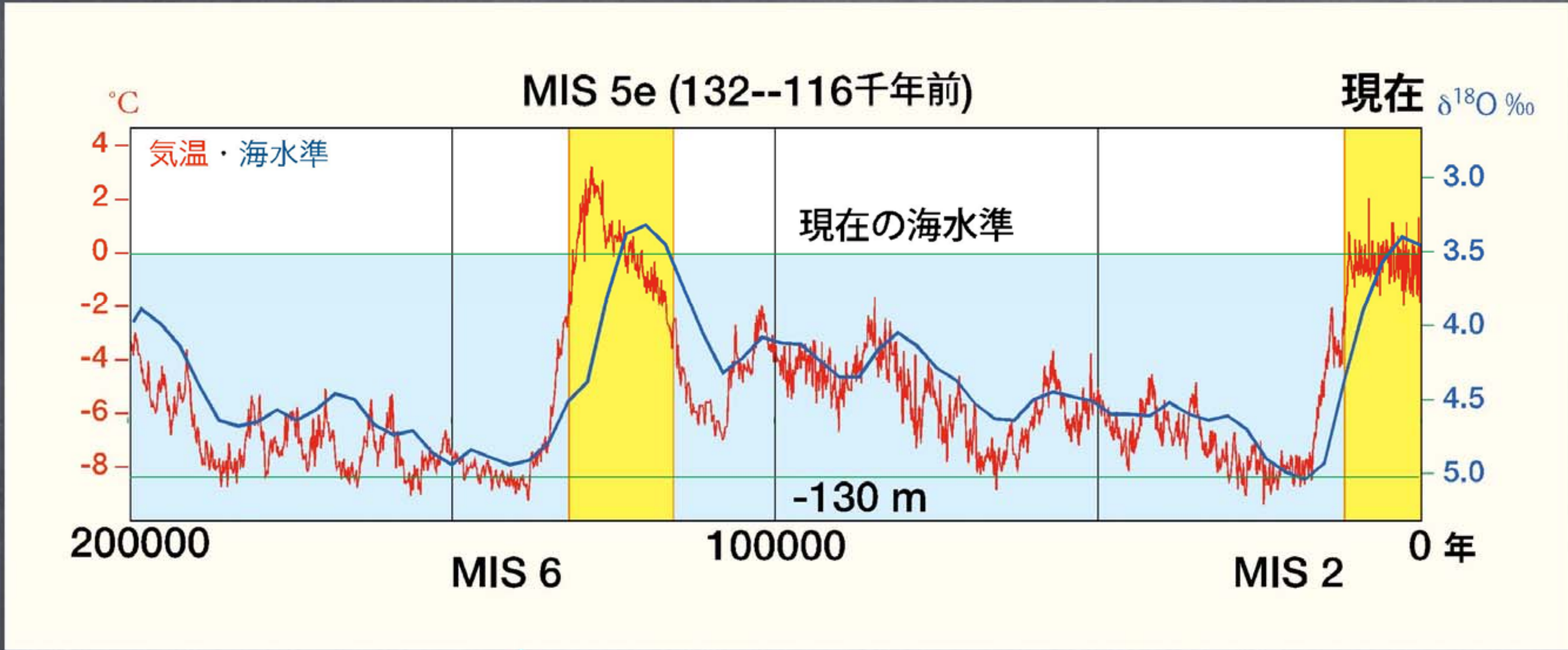


Mahalanobis distance between tephra in the lower part of the layer⑤ and other tephra

Mahalanobis distance (D^2)

- Indicates the distance between the centers of different groups (the lower the value, the greater the resemblance).
- In the case of two groups: $D^2 = (\mu_1 - \mu_2)^T \Sigma^{-1} (\mu_1 - \mu_2)$ However, note that μ is the average value while Σ is variance-covariance.

- Tephra was identified by focusing also on similarities in main ingredient composition.
- In order to determine similarities in the main ingredient composition in a more objective, quantitative fashion, we implemented DFA (Discriminant Function Analysis).
- As a result, it was judged that "the tephra in the lower part of layer⑤ is similar to Mihama tephra and NEXCO80 (lower)".



Last K fault activity

Potential faults and so on for future activities
(Active faults to be considered for seismic design)

Temperature for the past 200k years (Vostok base, the South Pole)
Sea water level fluctuation (Source; Lisiecki and Raymo (2005))